Everything You Always Wanted to Know About Microwave Remote Sensing of Sea Ice*

*But were afraid to ask ...

Walt Meier

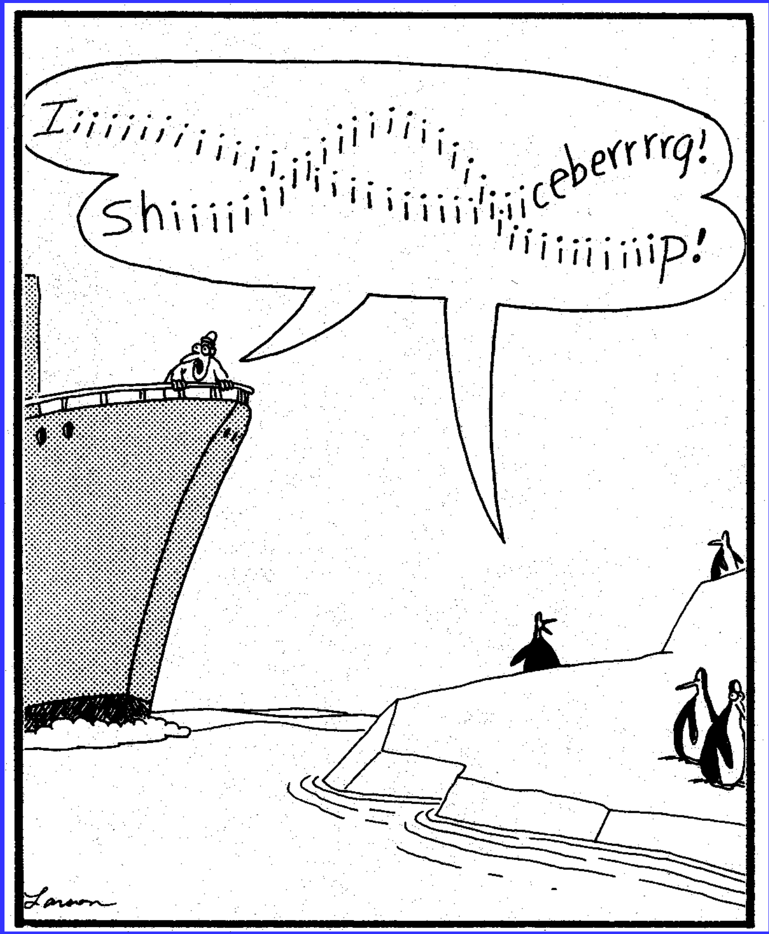
24 August 2000

Photo Courtesy J. Key

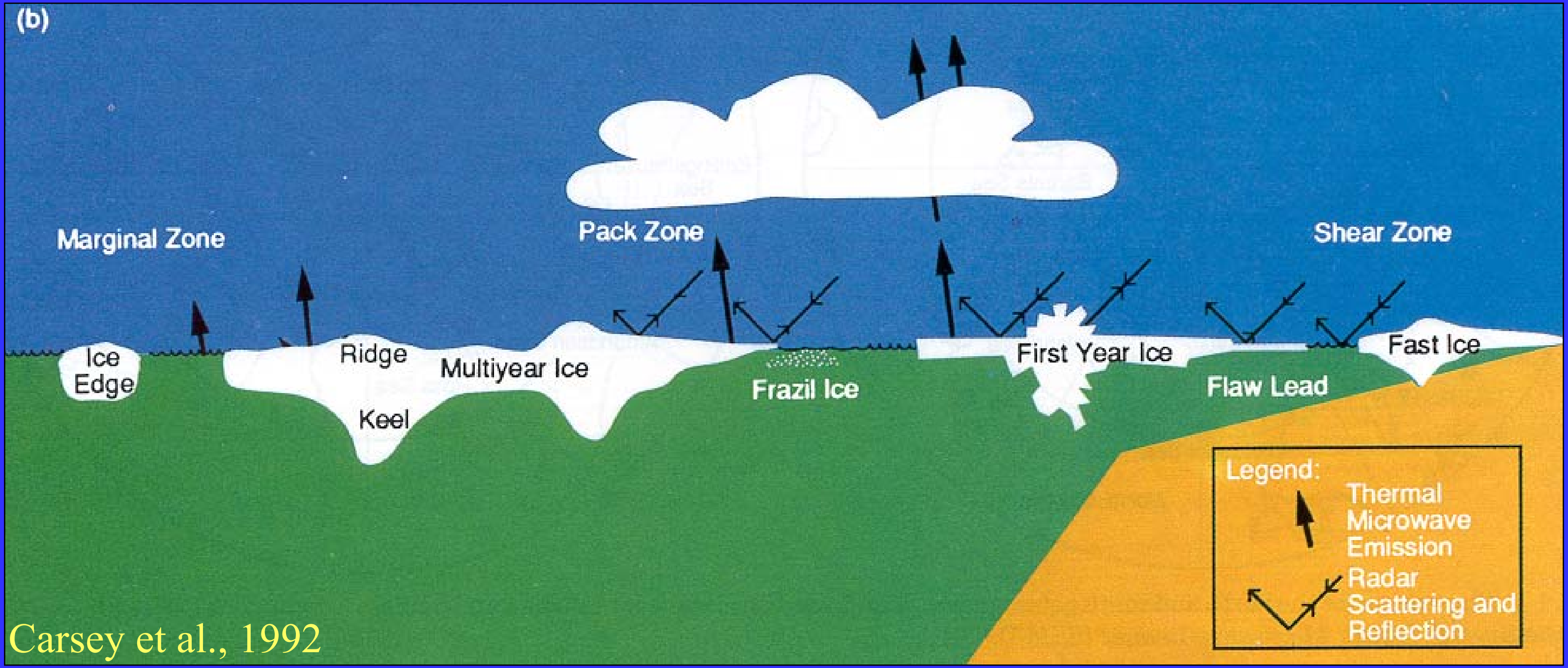
Coming Attractions

- Physical Basis of Microwave Remote Sensing
- Passive Microwave Remote Sensing
- Special Sensor Microwave/Imager (SSM/I)
- SSM/I Ice Concentration Algorithms

Physical Basis for Microwave Remote Sensing of Sea Ice

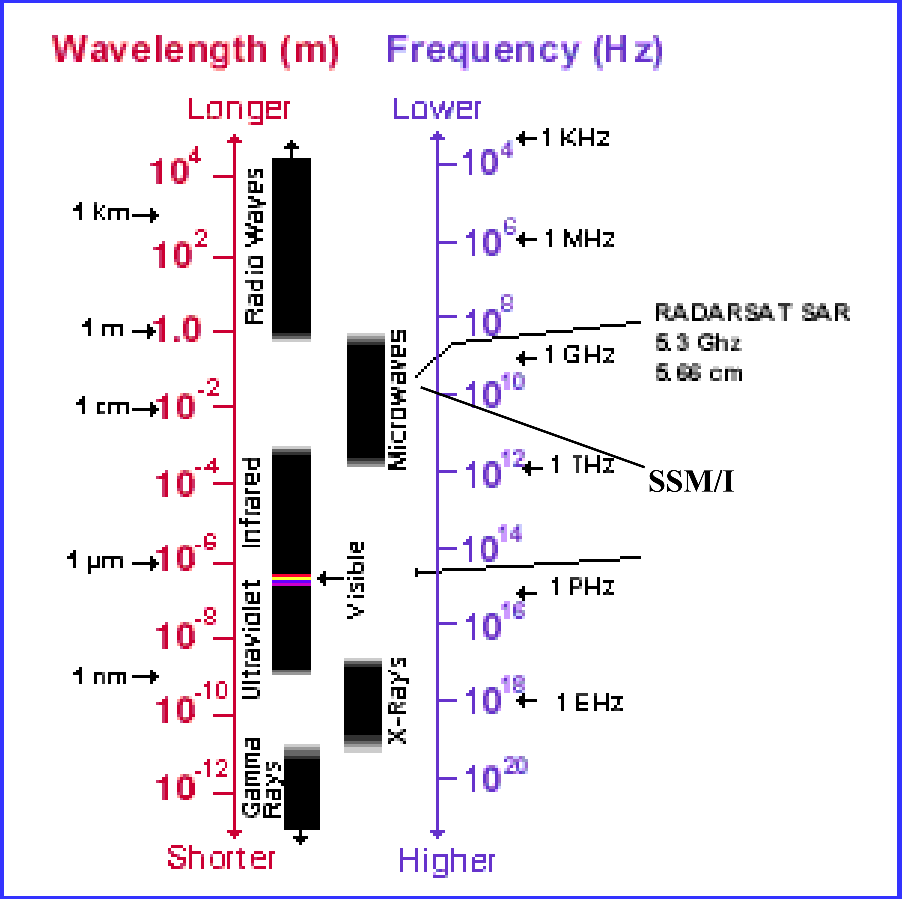


Microwave Emission and Scattering in Toontown



Carsey et al., 1992

Somewhere Over the Electromagnetic Rainbow



Microwaves:

1 GHz - 300 GHz
30 cm - 1 mm

From: http://www.ccrs.nrcan.gc.ca/ccrs/eduref/tutorial/indexe.html

Passive-Aggressive Behavior of Microwave Sensors

- Passive (Radiometers)
  - sensor detects natural emission from earth
  - emission from surface, near-surface, and atmosphere (and space)
- Active (Radars, Scatterometers)
  - sensor emits radiation and measures its reflection or backscatter
  - only some of emitted radiation is reflected back to sensor, rest is scattered

Passive Microwave Remote Sensing

T_B …

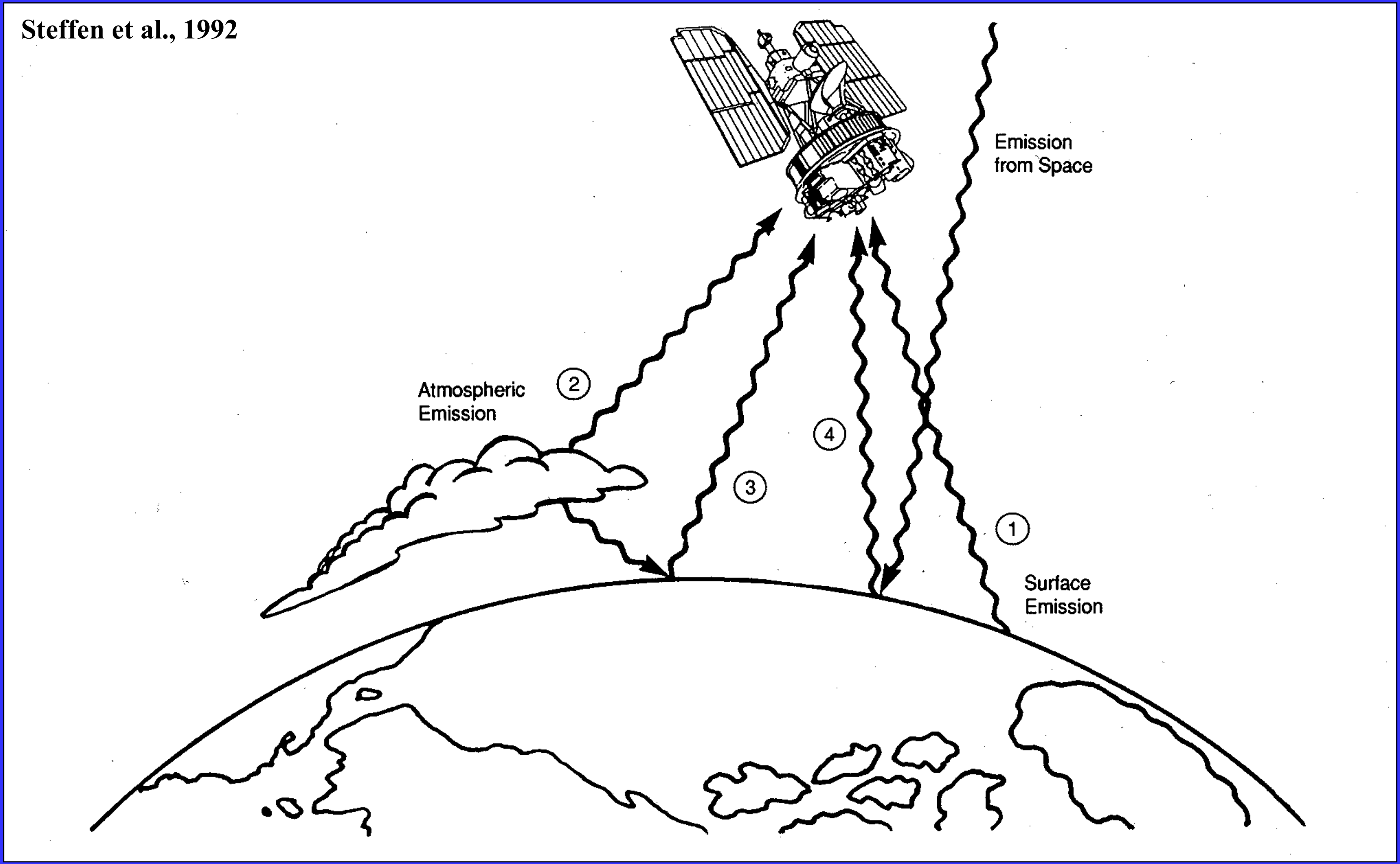
$$T_B[f,\theta] = \varepsilon[f,\theta] \times T_{physical}$$

- T_B - Brightness Temperature. Temperature at which emitting body would be if it were a black body. <u>Satellite observes T_B.</u>
- $T_{physical}$ - physical temp. of emitting body.
- ε - emissivity. Range from 0-1. Measures how close body is to blackbody.
- f - frequency; θ - polarization

...Or Not T_B

- Emission comes from different layers, and depends on frequency
  - snow surface
  - snow/ice interface
  - internal ice
- Brightness temperature is a function of the physical temperature. Thus, a body with same emissive properties will have a different T_B if $T_{physical}$ changes.

Squiggly Lines in the Sky



T_B = (1) surface + (2) direct atmospheric + (3) reflected atmos. + (4) reflected space

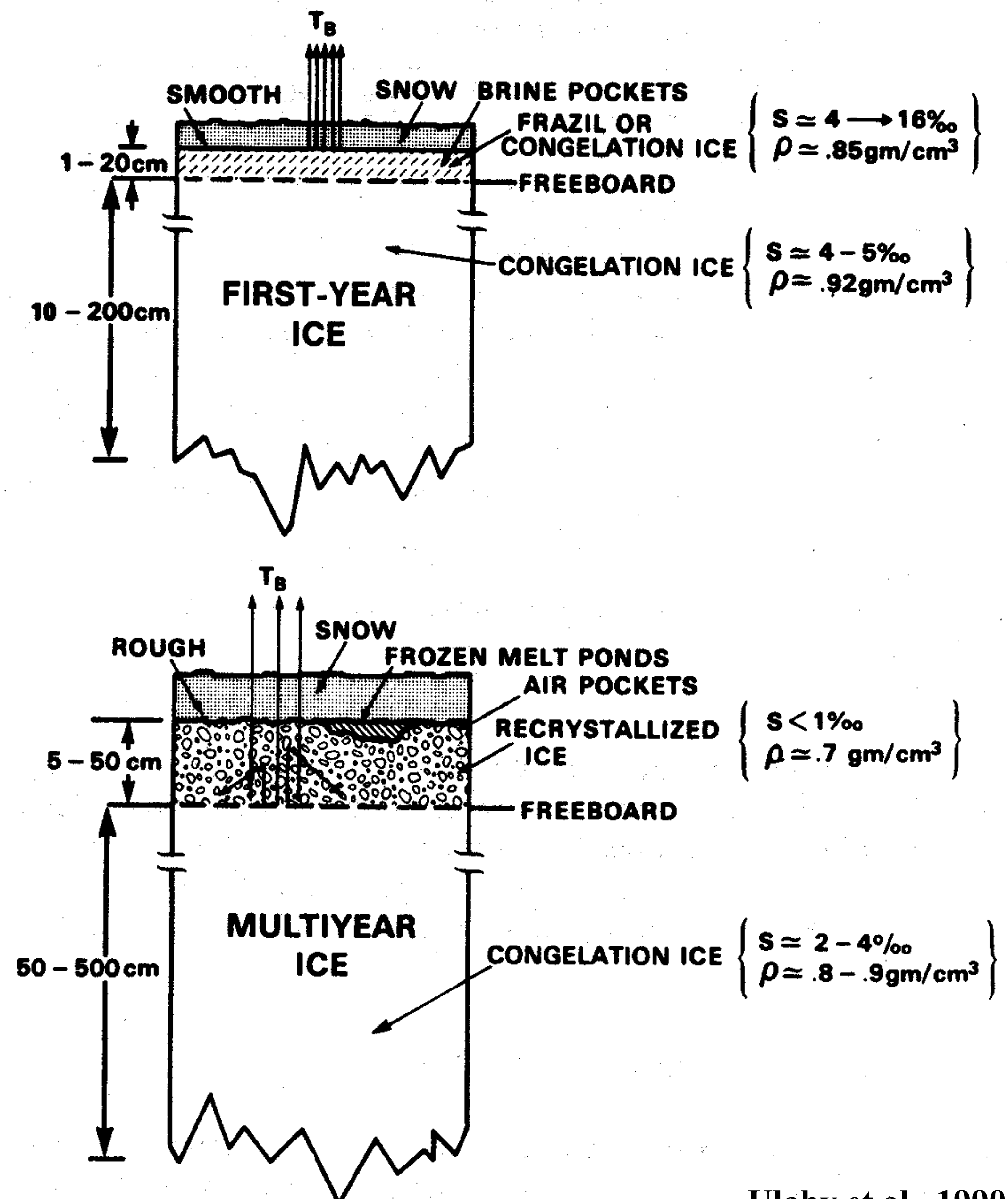
As Cold as Water…

- Open water is reflective in microwave band and emits little energy, i.e. radiometrically cold, and has strong polarization.
- First year ice is strongly emissive, i.e. radiometrically warm, and has weak polarization.
- Multiyear ice has a more complex and variable microwave signature; in general emission falls between water and FYI, with weak polarization.

…As Warm as Ice

- First year ice tends to have consistent thickness and surface roughness and entrained brine content
- Multiyear ice has lower salinity, with brine pockets replaced by air
- Multiyear ice can encompass many ice features: frozen melt ponds, ridges and hummocks, etc.
- Other factors:
  - water vapor - emission can obscure surface
  - snow cover - increase or decrease emission

Ice Ages



Ulaby et al., 1990

Battle of the Blue and the Gray: Arctic versus Antarctic Sea Ice

- Antarctic has much higher fraction of frazil ice (> 50% versus ~10% in Arctic)
- Antarctic primarily first year ice
- Multiyear ice in the Antarctic retains high salinity characteristic of FYI because of sea water flooding
- Almost no melt ponds in Antarctic

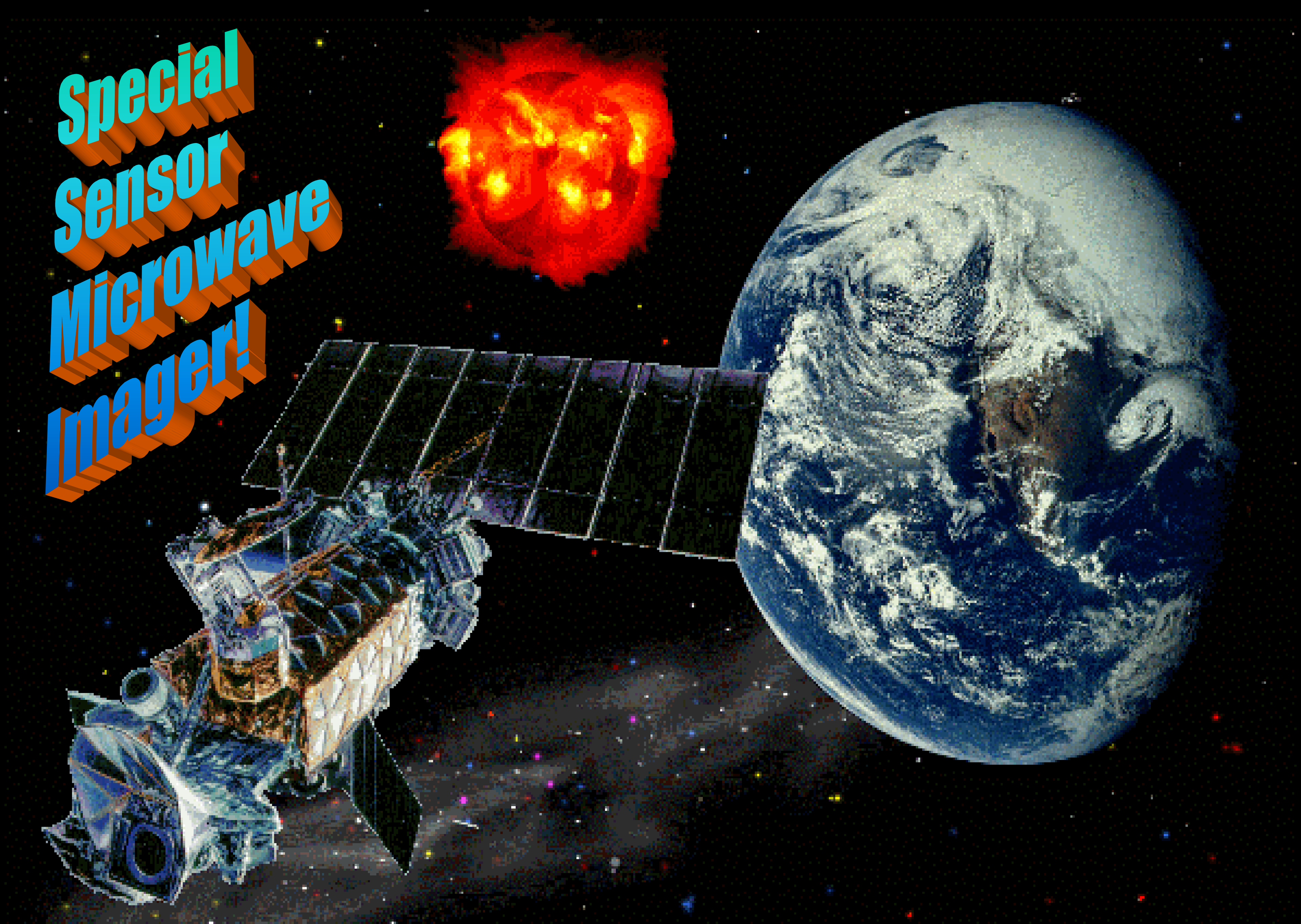


Image: http://www.ngdc.noaa.gov/dmsp/dmsp.html

SSM/I Vital Statistics

- Four Frequencies
  - 19.3 GHz
  - 22.2 GHz (water vapor)
  - 37.0 GHz
  - 85.5 GHz
- Dual polarization (horizontal and vertical), except for 22 GHz → 7 channels
- Resolution depends on frequency
  - 19, 22, and 37 GHz gridded to 25 x 25 km
  - 85 GHz gridded to 12.5 x 12.5 km

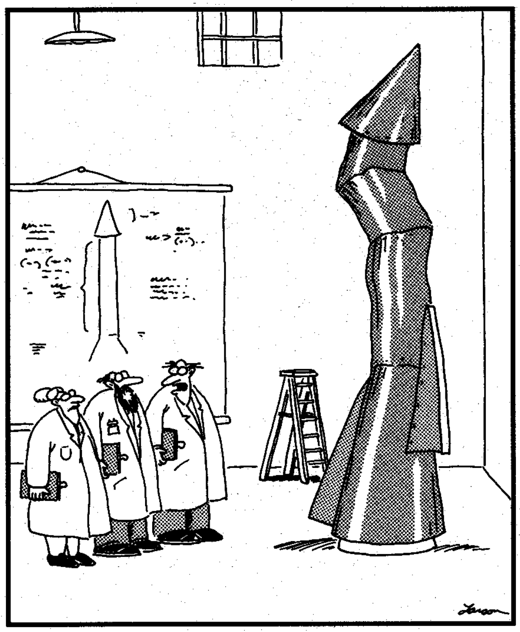
DMSP Vital Statistics

- SSM/I flown on the Defense Meteorological Satellite Program platform, run by Dept. of Defense
- Altitude: ~830 km
- Orbit period: 101 minutes (~14 orbits/day)
- Near circular, sun-synchronous, polar orbit
- Scan width: ~1400 km (for SSM/I)
- Twice-daily complete coverage above 60 degrees latitude
- DMSP also includes the Optical Line Scanner

The DMSP Family

- F1: First DMSP Satellite, 1976
- F8: First DMSP with SSM/I, June 1987
- F10: December 1990 - November 1997
- F11: November 1991
- F12: August 1994, SSM/I died
- F13: March 1995
- F14: April 1997
- F15: December 1999

—— currently in operation



"It's time we face reality, my friends. ... We're not exactly rocket scientists."

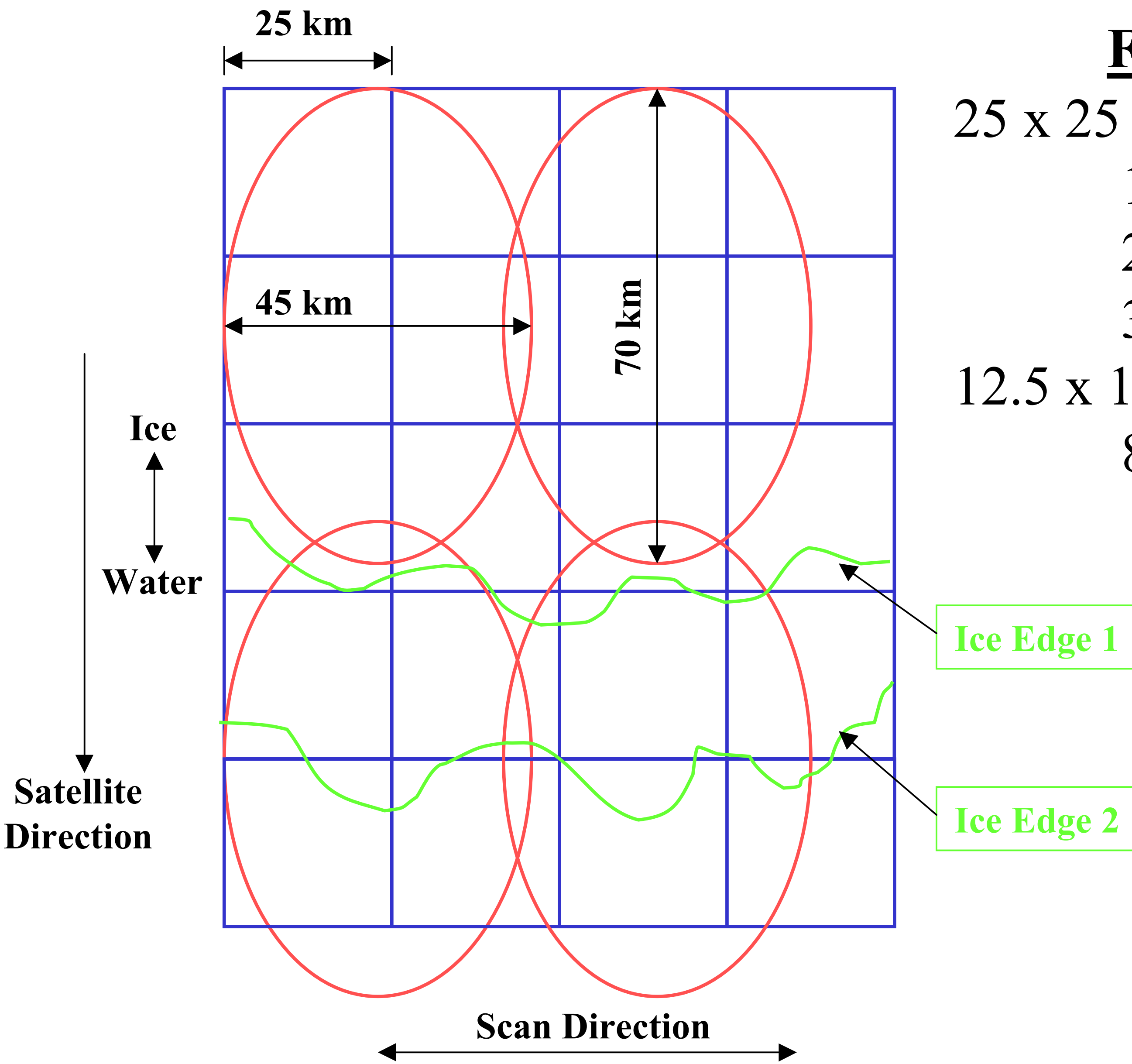
From Outer Space to Your Desk: The Journey of SSM/I Data

- SSM/I sensor measures microwave emission of sea ice
- Data calibrated onboard by hot and cold plates to antenna temperatures (T_A)
- Data transmitted to downlink sites
  - Air Force Global Weather Control (AFGWC), Offutt AFB, Nebraska (NOAA Level 1b Data)
  - Fleet Numerical Meteorological and Oceanographic Center (FNMOC), Monterey, CA (TDR Files)
- FNMOC converts TDR files of T_A into T_B
- FNMOC runs ice concentration algorithms, grids data, and sends to NIC

Review Question:

What is the resolution of the 19.3 GHz channel on SSM/I?

Bigfoot - The Footprint Issue



Footprint Sizes

25 x 25 km Grid:

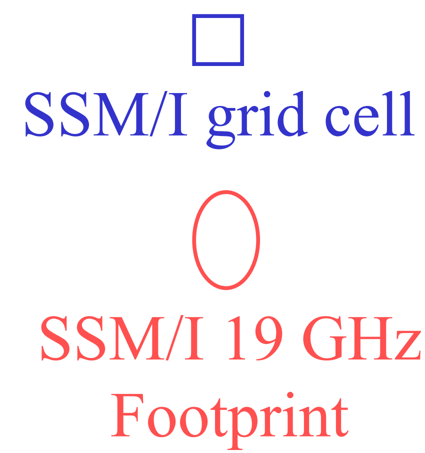
19 GHz: 70 x 45 km

22 GHz: 60 x 40 km

37 GHz: 38 x 30 km

12.5 x 12.5 km Grid:

85 GHz: 16 x 14 km



The Good, the Bad,...

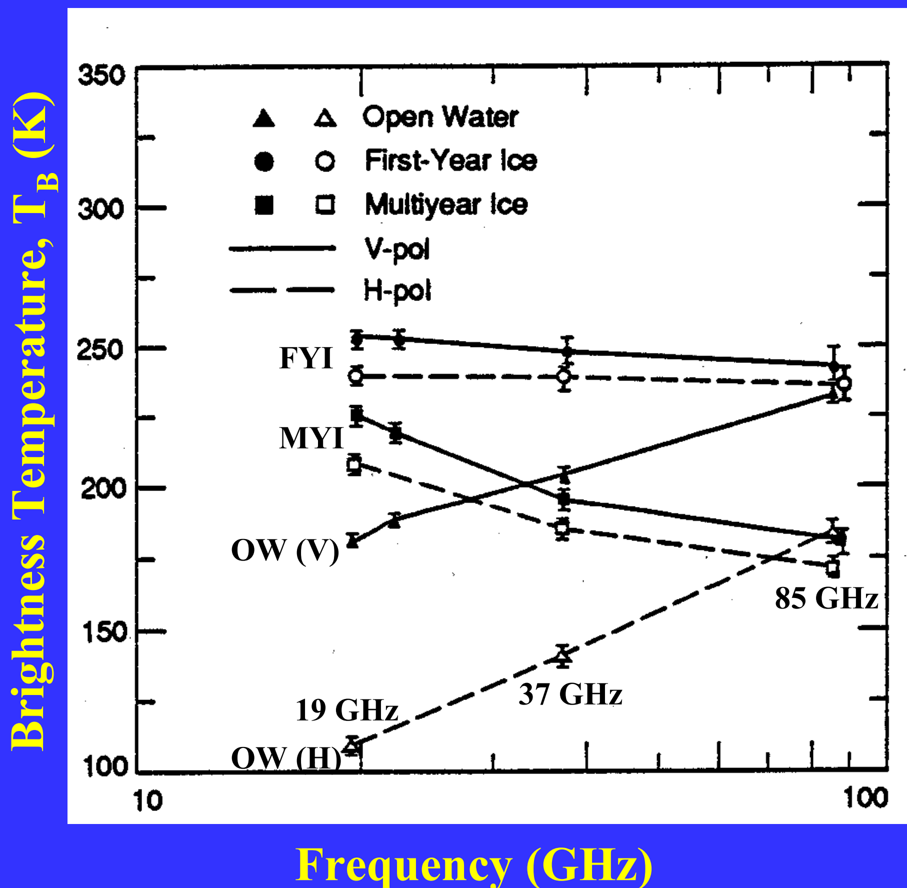
- Advantages of SSM/I
  - complete daily coverage of Arctic and Antarctic
  - independent of solar radiation
  - detects surface emission through clouds at 19 and 37 GHz
  - can yield some ice type information
- Disadvantages of SSM/I
  - emission from water vapor, clouds, rain can affect signal (especially 85 GHz)
  - difficulties during summer melt season (e.g., meltponds and surface water)

…and the Ugly

- Low spatial resolution (ice edge)
- Many operationally relevant ice types (e.g., new ice, young ice, pancake ice) cannot be resolved unambiguously
- Difficulties in marginal ice zones
- Underestimation of thin ice concentration
- Contamination of coastal pixels (effects on polynyas)

SSM/I Ice Concentration Algorithms

Ice from SSM/I's Point of View



- Open water much colder radiometrically than ice at 19H and 37H
- Open water has large polarization difference compared to ice
- T_B difference between 19 and 37 GHz larger for multiyear ice

A Couple of Equations

Polarization Ratio:

$$PR_{[19V/H]} = \frac{T_B[19V] - T_B[19H]}{T_B[19V] + T_B[19H]}$$

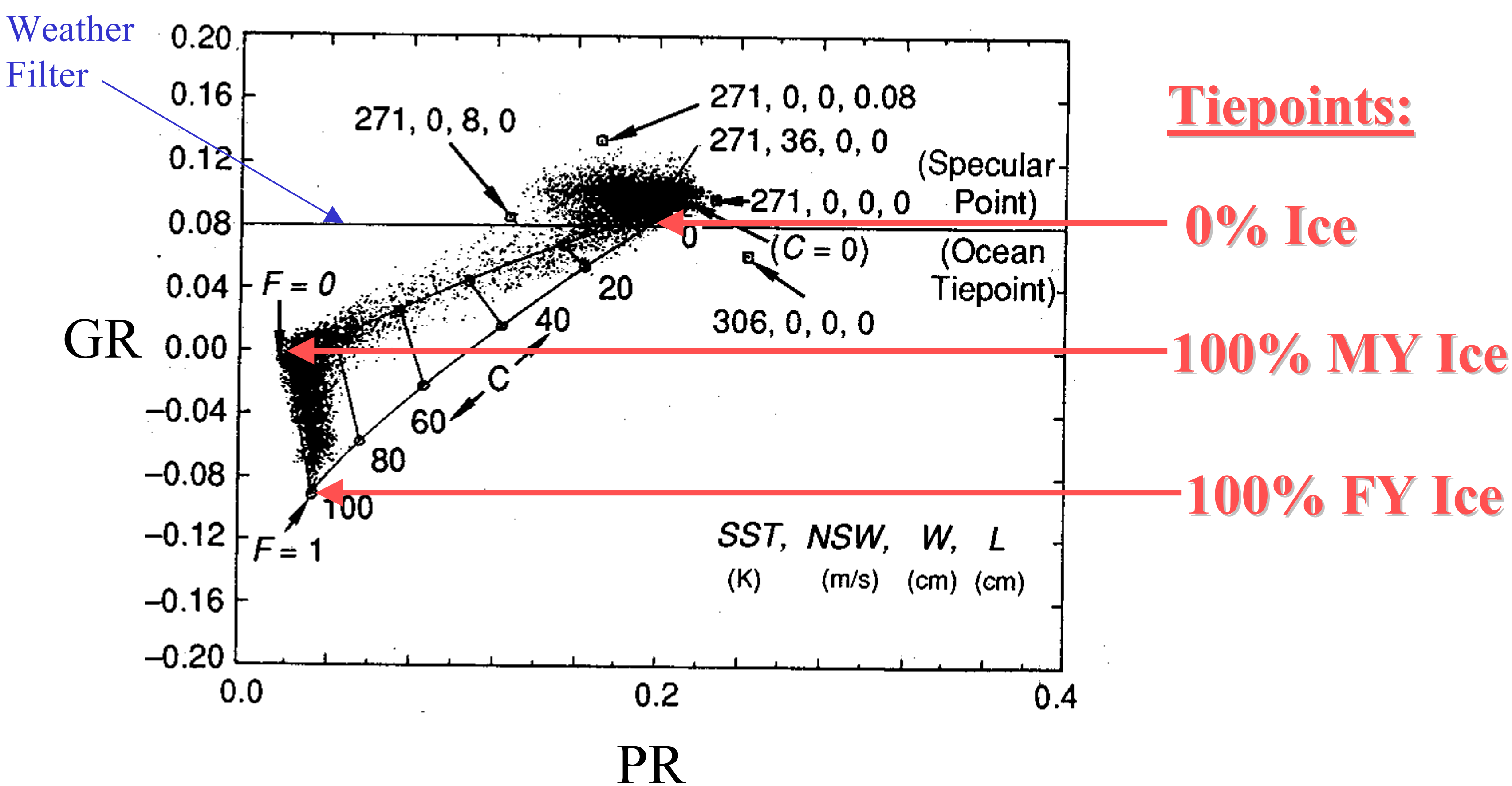
Large for water
Small for ice

Gradient Ratio:

$$GR_{[37V/19V]} = \frac{T_B[37V] - T_B[19V]}{T_B[37V] + T_B[19V]}$$

Larger for MYI
Smaller for FYI

Triangle Power - The NASA Team Algorithm



Poor ‘Team’ Effort: Problems with NASA Team

- Low resolution at ice edge (dependent on 19 GHz footprint)
- Poor detection of thin ice (high concentrations of thin ice detected as mixture of thicker ice and open water) due to the use of hemispheric tiepoints

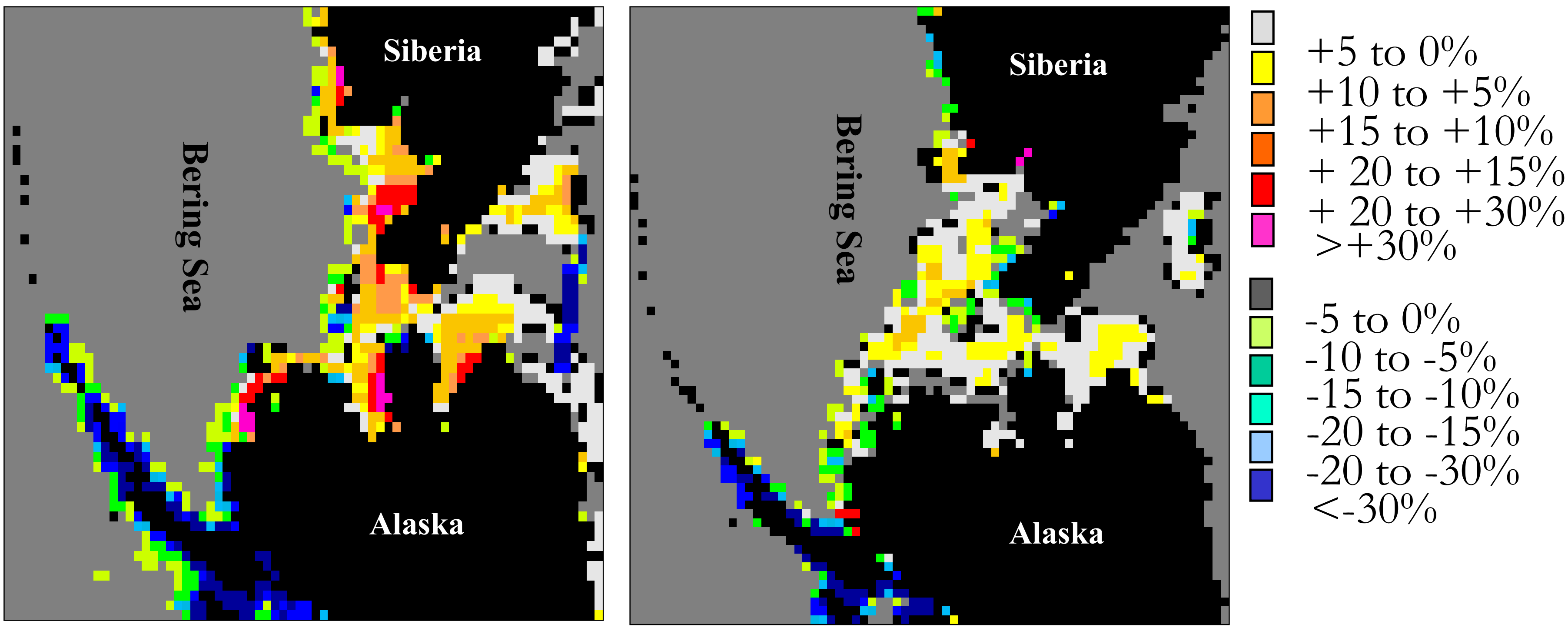
Cal and Val to the Rescue: The Cal/Val Algorithm

- Operational standard at NIC
- Developed for calibration/validation of SSM/I
- Uses only 37 GHz near ice edge
- Sensitive to presence of ice (detects thin ice well)
- Tends to saturate (does not detect small variations at high concentrations)
- No information on ice type

NASA Team Strikes Back! The Thinteam Algorithm

- Uses ice edge from Cal/Val (higher resolution)
- Uses NASA Team with modified tie points in thin ice regimes
- Performs comparably with Cal/Val, but yields more realistic variability in ice pack
- Theoretically, three ice types
- Now produced as a secondary product by FNMOC

Exhibit A - Algorithm Differences



Cal/Val - NASA Team[1]
Dec. 9, 1998

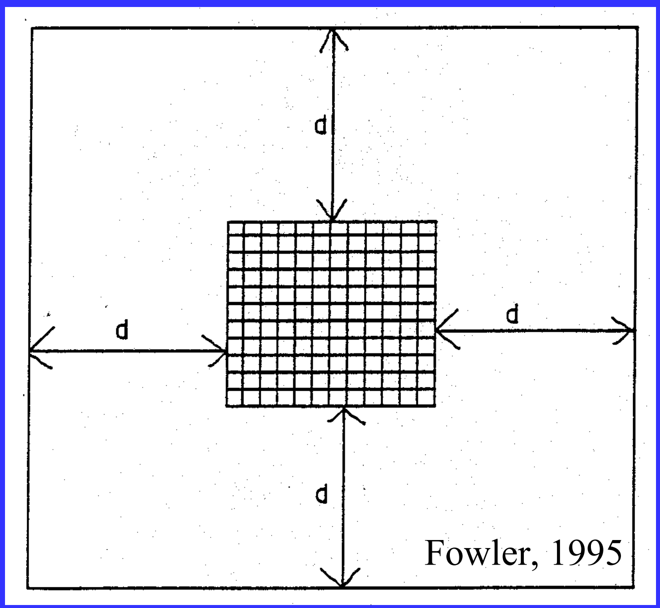
Cal/Val - Thinteam
Dec. 12, 1999

[1]Thanks to K. Partington

The Drunken Sailor's Walk: An SSM/I Ice Motion Product

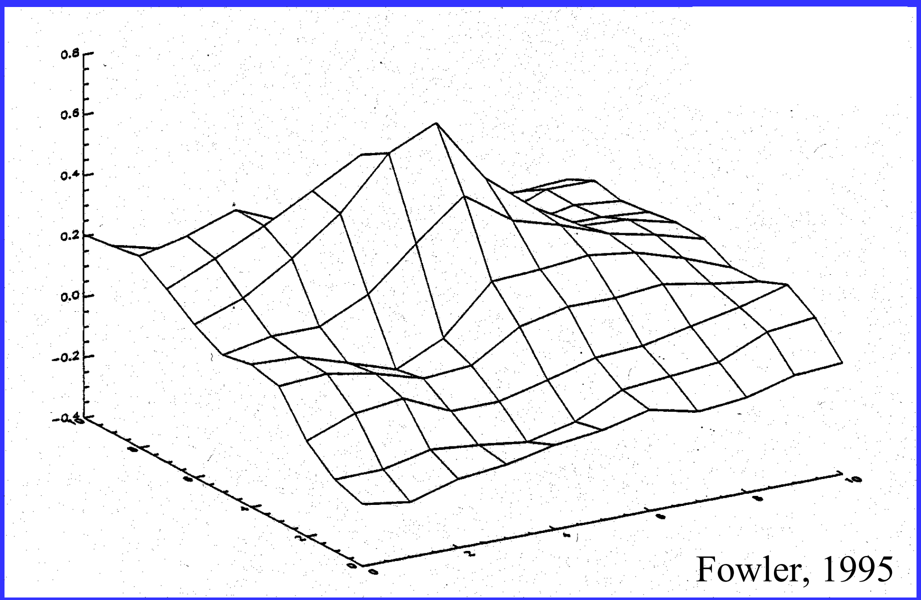
- Uses 85 GHz channel (higher resolution)
- Cross-correlation scheme to match pixels in sequential images
- Filtering to eliminate weather effects
- Limited by resolution
- Not useful during summer
- New product being sent by FNMOC

Hide and Seek



Fowler, 1995

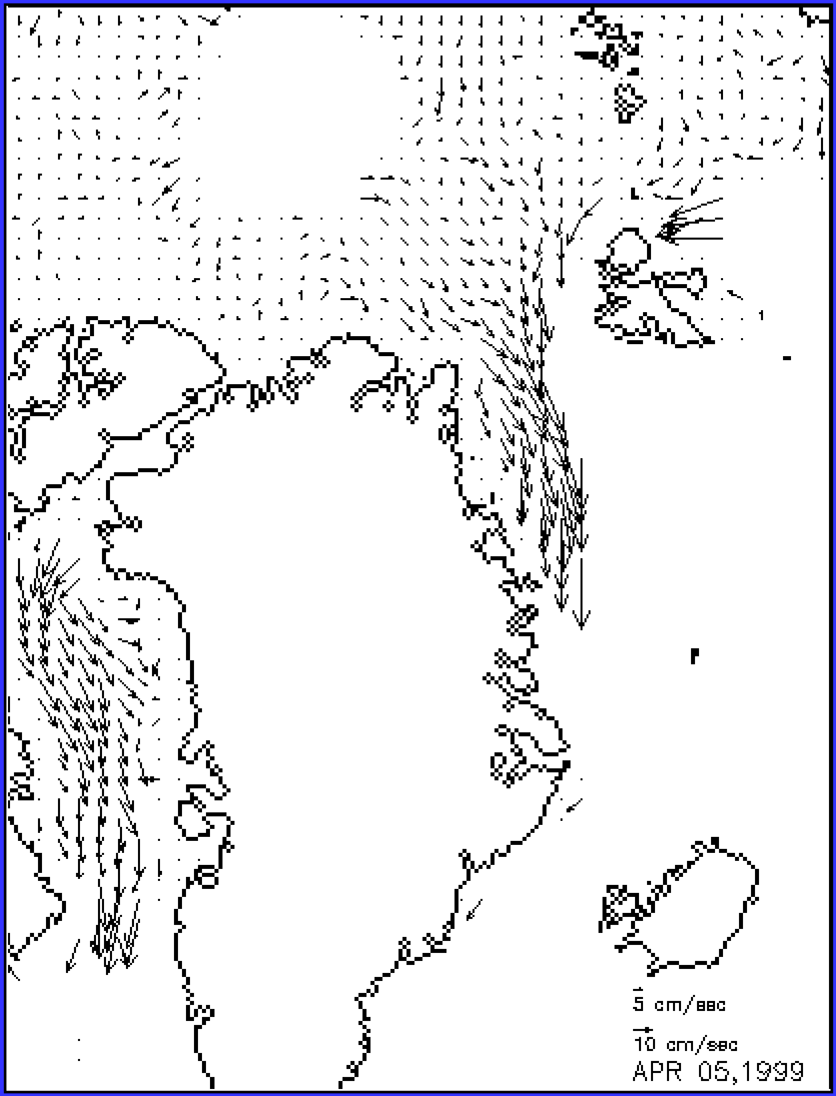
a) Move box distance ‘d’ in each direction and compute correlation.



Fowler, 1995

b) Find best match (correlation peak). That is where parcel has moved.

Ice on the Move



http://polarbear/colorado.edu/RT_SSMI.html

The Future's So Bright, We Gotta Wear Shades:

- NASA Team 2 - Markus and Cavalieri, 2000
  - uses 85 GHz and radiative transfer model (for atmospheric effects) to obtain additional information
  - substantial improvement over NASA Team
- AMSR
  - Advanced Microwave Scanning Radiometer
  - up to 5 km resolution (much better ice edge detection and ice motion)

Any Other Questions?


The End

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